MEMORY CONSOLIDATION AS A FUNCTION OF SLEEP
AND THE CIRCADIAN RHYTHM

By

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A DISSERTATION PRESENTED TO THE GRADUATE COUNCIL OF
THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE
OF DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA

1974

To my Mum and Dad

ACKNOWLEDGEMENTS

I wish to express my deep gratitude to the Chairman of my Supervisory Committee, Dr. C. Michael Levy, for his help and support throughout my graduate career. I am also deeply indebted to the members of my Supervisory Committee Dr. Wilse B. Webb, Dr. Hugh Davis, Dr. Henry Pennypacker and Dr. David T. Hughes, for their advice and assistance. Special appreciation is due to Jean Street, Cindi Edge, Lou Silverstein, and my wife for their help in this research project.

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August, 1974

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The purpose of this study was to investigate the relation-
ship between short- and long-term memory as a function of
circadian placement and to determine the effects of sleep or
wakefulness during the retention interval on long-term verbal
and visual memory. One-hundred college students in an intro-
ductory psychology course participated as Ss, with 10 Ss
assigned to each Time Period x Sleep-Wakefulness combination.
The time periods were 3 hr. in length and began at 8:30 AM,
11:30 AM, 2;30 PM, 5:30 PM and 8:30 PM. After each S was wired
for EEG recordings he was tested for both verbal and visual
short-term memory. The verbal test consisted of a series of
16 common nouns and assessment of learning was determined by
free recall. The visual test consisted of a series of 20 facial
photographs and assessment of learning was determined by a four-
alternative multiple choice test. During short-term memory
testing the Ss were led to believe they would not be tested
again on the list of words in order to control for rehearsal

and were presented with 20 additional photographs for a test of visual long-term memory. The $\underline{S}$s retired to separate rooms and the $\underline{S}$s in the sleep conditions were told to relax and sleep. The $\underline{S}$s in the awake conditions were given a puzzle and a deck of cards and were told to relax and remain awake. Two hours later all $\underline{S}$s were tested by free recall for the list of words and for recognition of the second series of photographs.

The results indicated that although significant differences in sleep stage characteristics between sleep conditions were established, there were no significant differences in long-term memory between $\underline{S}$s in the sleep or wakefulness conditions nor were there any significant fluctuations in long-term memory with temporal placement. Analyses of short-term verbal and visual memory revealed no consistent variations across time periods, although there was some evidence to indicate that short-term memory may increase in either efficiency or capacity as a function of time-of-day. Overall, it appeared that neither time-of-day nor sleep in the retention interval contribute a substantial amount of variance to the phenomenon of forgetting. In addition, it was suggested that the typical sleep-memory experimental paradigm may be inappropriate to test the hypothesis that sleep affects memory consolidation since the perseverative consolidation of long-term memory may be completed before the onset of sleep.

CHAPTER I
INTRODUCTION

Memory has been shown to be better after sleep than after wakefulness (Jenkins & Dallenbach, 1924; Van Ormer, 1932; Ekstrand, 1967) and this finding has been a provocative source of research for almost 90 years. Ebbinghaus, in 1885, first noted the effect when he found that the rate of forgetting between an 8.8 hr. interval and a 24 hr. interval was not as great as between 1 hr. and 8.8 hr. or 24 hr. and 48 hr. intervals. Sleep formed a significant part of the 24 hr. interval but Ebbinghaus dismissed sleep as a cause and sought an explanation among the accidental errors of his experiment. In 1913 Foucault suggested, however, that the discrepancy between the intervals was due to the predominance of sleep in the 24 hr. interval and hypothesized that sleep prevented inhibition produced by daily activities. In 1914 Heine tested this hypothesis with four Ss after 24 hr. when nonsense syllables were learned before going to bed and when they were learned with waking intervals interpolated between the learning and sleep. She found reliable differences in favor of the sleep-after-learning condition.

Foucault (1913) was the first to interpret the facilitating effect of sleep in terms of an interference theory of forgetting and this interpretation was to serve as one of the empirical bases of evidence for interference theory. The theory assumes that forgetting is a result of learning competing responses

either before acquisition of the criterion response or in the retention interval. Sleep would serve to reduce the latter source of interference. However, there are at least two other explanations which may account for the facilitating effect of sleep. First, the trace decay theory holds that forgetting occurs as a result of decaying memory traces and the decay of memory traces may be slower during sleep. The second interpretation involves a consolidation theory of memory and assumes that learning results in formation of neural traces which require a perseverative period to insure their recallability. It is possible that sleep protects the perseveration process from disruption.

The facilitating effects of sleep upon memory became well known with the classic study by Jenkins and Dallenbach (1924). In their study two male college students participated over a period of three months. Their task was to memorize a series of 10 nonsense syllables which were individually pre-sented and repeated aloud by the Ss upon presentation. After a period of 1, 2, 4 or 8 hr. of sleep or wakefulness, reten-tion was measured by free recall. The times of learning during the night varied between 11:00 PM and 1:00 AM and in the morn-ing between 8:00 AM and 10:00 AM. When the learning occurred at night, the Ss were ready for bed and retired upon completion of the learning and were awakened after specified intervals. After learning in the day, the Ss went about their routine affairs.

Twice as many syllables were reproduced after periods of sleep than after periods of wakefulness. There was also better

recall after 1 hr. of sleep than after 2, 4 or 8 hr. but there were no differences in recall between the 2, 4 and 8 hr. intervals of sleep. Recall decreased progressively during the waking intervals.

Jenkins and Dallenbach speculated that forgetting was not so much a matter of the decay of original impressions and associations as it was interference, inhibition and obliteration of the original by the new, and postulated that sleep prevented new learning and minimized retroactive interference.

Although experimentally sound for its time the study of Jenkins and Dallenbach had a number of potentially confounding variables. First, there was the possibility of proactive interference because of the continued use of two Ss for three months. Proactive interference may have depressed recall in the latter stages of their experiment and might have differentially influenced the sleep and wakefulness conditions due to incomplete counterbalancing in the number of replications in the 1 hr. and 2 hr. wakefulness conditions.

Second, the learning and recall of the daytime series was closer in time to previous learning and recall than was the learning and recall at night. Thus, the possibility exists that proactive interference was much greater for daytime learning and consequently, daytime recall could have been lower. A third confounding variable was that learning during the night required more repetitions to criterion than did daytime learning. As a result, nighttime learning may have been better learned or overlearned and could have led to the superiority of the recall after intervals of sleep. Because of nonsophisti-

cated statistical treatment procedures available in that era,
Jenkins and Dallenbach were unable to determine whether the
extra repetitions at night were statistically reliable. How-
ever, over the three month period one S required an average
of one more repetition at night and the other S required two
more repetitions at night.

In order to document further an interference theory of
forgetting, Van Ormer (1932) replicated Jenkins and Dallen-
bach's study. The learning materials were lists of three-
letter nonsense syllables. The S anticipated the correct re-
sponse after the first presentation until the first correct an-
ticipation of the list of syllables. Night learning occurred
between 11:00 PM and 12:00 AM and day learning occurred between
9:00 AM and 10:15 AM. Retention was measured by the number of
trials taken to relearn the lists. The experiment lasted four
months.

A summary of the results revealed a clear advantage of
sleep over waking in the number of trials taken to relearn the
materials at the 8 hr. interval; there was a slight advantage
of sleep over waking at the 4 hr. interval, and no clear ad-
vantage of sleep over waking at the 1 or 2 hr. intervals. Van
Ormer also noted that learning in the morning and early after-
noon required fewer trials to criterion than in the late evening.

Van Ormer suggested that sleep facilitated recall by pre-
venting inhibiton and obliteration of the learned material by
waking activity. He postulated the existence of perseveration
processes which consolidate memory and hypothesized that these
processes may be inhibited by waking activity. Van Ormer

postulated a revision of the law of disuse: Forgetting is a function of the nature of the interpolated experience, the altered environmental contexts, and the organic state of the individual during and subsequent to learning, rather than being an intrinsic function of the interval of disuse.

Similar to the Jenkins and Dallenbach study, Van Ormer's design allowed for a number of confounding variables. First, using only himself and his wife may have allowed for experimenter bias to influence the data. Second, massive amounts of proactive interference could have had depressing influence on learning in the latter part of the experiment because of the continued use of two Ss for four months. Finally, there was a lack of statistical treatment of the data.

Lovatt and Warr (1968) attempted to determine whether waking retention in the Jenkins and Dallenbach study might have been depressed for all items equally, irrespective of the degree of learning. In their experiment college students served in a daytime and nighttime condition. The paced-anticipation method of learning a list of paired-associates was employed. Recall was assessed by a single presentation of the stimuli. Recall was significantly better after sleep than after wakefulness. Learning was also significantly more rapid in the morning than at night. The degree of learning, however, did not appear to be the cause of superior nighttime retention. Of the 40 Ss, 20 required more learning trials at night than they did in the morning and 13 of the 20 had better retention overnight. However, there were 13 Ss who required more learning trials in the morning, yet only two of these 13 Ss showed

better retention after a daytime interval. Thus, if a larger number of trials to criterion alone results in better retention, then, more than just two of the 13 Ss should have shown better retention after the daytime interval. This clearly was not the case and it appears the sleep-wakefulness interval was responsible for differential forgetting and not the degree of learning.

Ekstrand (1967) hypothesized that sleep provided an environment conducive to spontaneous recovery of original learning by elimination of interpolated learning. In his experiment 120 male college students learned either one list or two lists of 12 pairs of three letter words and adjectives. For the single list Ss, half of the Ss learned and recalled one of the lists and half the other. The Ss learned the required lists to a criterion of one perfect recitation. Learning in the sleep conditions occurred from 10:00 PM to 11:00 PM while learning in the wakefulness condition varied from 8:00 AM to 1:00 PM. Eight hr. after the learning sessions were completed, each S was given a warmup task (number guessing), a free recall trial and a stimulated recall trial of the single or the pair of lists. Next, the Ss were required to match stimuli and responses.

On the single list free recall and on stimulated recall the Ss in the sleep condition recalled significantly more response pairs than the Ss in the wakefulness condition. The matching test revealed almost perfect recall for both groups although the sleep Ss were slightly better.

On double list free recall, retention of the second list was superior to recall of the first list, although there was no significant difference between sleep and waking conditions. On stimulated recall and matching there was significant difference in favor of the sleep conditions on retention.

Ekstrand noted three possible interpretations of this facilitating effect of sleep upon memory: (a) sleep facilitates the consolidation of the memory trace, (b) sleep, as a function of being associated with a lower metabolic rate, slows the rate of decay of the memory trace, and (c) forgetting is produced from interpolated learning and sleep produces an environment which protects memory from interpolated learning and allows for spontaneous recovery. Ekstrand's experiment, however, did not present evidence which favored or eliminated any one of these interpretations.

The facilitating effect rather than the "protective" effect of sleep on memory has also been interpreted in terms of a consolidation theory of memory. Müller and Pilzecker (1900) made the first statements concerning consolidation processes in memory and deemed these processes as crucial to efficient retention. They postulated that any interference with the perseverating process would have an adverse effect on the organism's ability to remember the original stimulus. Hebb (1949) described this process at a molecular level and hypothesized that there were reverberatory circuits or activity which maintained the memory trace until the permanent changes which were associated with the fixation of the trace were completed.

Duncan (1949) found that these "reverberations" could be interfered with by electroconvulsive shock and his work with rats indicated that deficits in retention could be produced by applying shock after a learning trial. The magnitude of the effect decreased as the trial-shock interval increased which produced a negatively accelerated curve. Later work (Thompson & Dean, 1955; Leukel, 1957) confirmed that deficits in retention could be produced if the shock was delivered from within 15 to 60 min. following a learning trial.

Investigation of consolidation theory and sleep have focused upon the facilitative effect of particular stages of sleep. Typically, sleep is monitored electroencephalographic-ally and five distinct sleep stages have been identified (Kleitman, 1963). The stages are known to come in periodic cycles throughout the night, although stage 4 which is a deep, dreamless state tends to predominate early in the night and REM sleep or dream sleep occurs predominantly in the latter third of a night's sleep (Webb & Agnew, 1967). One group of investigators has hypothesized that REM sleep may be the source of the facilitating effect (Feldman, 1970; Adelman & Hartmann, 1968; Empson & Clarke, 1970). Another group has suggested that stage 4 sleep may be responsible (Yaroush, Sullivan & Ekstrand, 1971; Fowler, Sullivan & Ekstrand, 1973; Barrett & Ekstrand, 1972; Hockey, Davies & Gray, 1972).

The investigations involving REM sleep have employed a sleep stage deprivation paradigm where retention is measured after selective sleep stage deprivation of either stage 4 or REM sleep. Deprivation may be accomplished by awakening the

Ss by hand, sound, or drugs. It is interesting to note that only a few studies employing the sleep stage deprivation paradigm involved stage 4 deprivation in humans.

Feldman (1970) tested four possible relationships between REM sleep and memory in a REM sleep deprivation paradigm. The hypotheses were (a) memory consolidation occurs and is completed during REM, (b) memory consolidation is only initiated during REM and its appearance occurs sometime after, but not immediately subsequent to that sleep period, (c) REM deprivation impairs short-term memory or material presented shortly after termination of that sleep period, and (d) REM assists in preparing the S to consolidate memories learned shortly following the termination of that sleep period.

The first experiment involved one night of REM deprivation. The Ss learned lists of words and numbers prior to REM deprivation and recalled them afterwards. They learned additional material after REM deprivation and recalled both sets of material three days later. Feldman found no effect on immediate or delayed recall with interpolated REM deprivation. There was also no effect on learning after REM deprivation. However, there were lower savings scores for paired associates relearned three days later.

In the second experiment the Ss learned five sets of material following the second of two successive nights of REM deprivation or control awakenings, and relearned or recalled the materials seven days later. The results indicated that of the five tests one showed slower learning, one more rapid

learning and three showed no differences. The test which
showed a positive effect in the first experiment showed no
effect in the second experiment. In summary, there were no
positive findings of an effect of REM deprivation upon memory
or learning consistent across both experiments. However, Feld-
man noted that REM sleep may still influence learning capacity
or memory consolidation and this influence may vary with the
nature of the assessment materials.

Ekstrand, Sullivan, Parker and West (1971) tested the
effects of REM and stage 4 deprivation upon the spontaneous
recovery of A-B associations in an A-B, A-C paradigm. Ekstrand
(1967) previously demonstrated that when sleep occurred during
a retention interval following the learning of two lists, the
recall of the first list showed the effects of spontaneous
recovery. He suggested this recovery could have resulted from
the action of some physiological variable during sleep. Ekstrand
et al. reasoned that if stage 4 or REM was responsible, then
deprivation of stage 4 or REM should inhibit spontaneous re-
covery.

In their experiment, college students learned two lists of
words before sleep. The REM deprivation group was awakened
each time they entered REM sleep and the stage 4 deprivation
group was awakened when they showed signs of delta activity.
The number of average awakenings for these two groups was used
to wake a control group an equal number of times during stage 1
and 2. In the morning after 7 hr. of sleep the three groups
were given a warmup task, paced recall, modified free recall,

matching and a relearning test.

There were no significant differences between any of the
conditions on any of the measures of retention. However,
for the stage 4 deprived group there were significant negative
correlations between the percentage of stage 4 present and
amount of recall on two of the recall measures. Since this
correlation did not appear in the REM deprived and control
groups, the authors attributed the findings to chance. In a
study by Empson and Clark (1970) a REM deprived group had
significantly more stage 4 than a nonREM deprived group but
recalled significantly less. This indicates that stage 4
sleep may have a deleterious effect upon memory and the nega-
tive correlations obtained in the Ekstrand et al. study may
not have been due to chance.

Chernik (1972) noted that animal studies pertaining to the
effects of REM sleep deprivation on learning and memory have
come to the tentative conclusion that REM plays a part in some
way in learning and memory processes although there are a
number of serious methodological drawbacks in these studies.
In her experiment college students spent three nights in the
study, the first of which served as an adaptation night. The
experimental Ss were REM deprived for two nights and control
Ss were awakened an equal number of times and for an equal
length of time but in nonREM sleep. The experimental and
control Ss were all previously matched on the basis of a paired
associate task. A verbal learning task of paired words was
administered on Wednesday afternoon prior to two nights of

deprivation, on the following Friday after two nights of deprivation and on Saturday after recovery sleep. The Ss were tested on one-half of the original list after sleep stage deprivation and on the other half after recovery sleep. The post-recovery test was given to determine whether performance differences observed were caused by retention or retrieval effects. If retrieval alone after deprivation accounted for a decrement, then the performance should be better on the post-recovery test. The Ss were tested on the paired associate task by the paced recall method. On Friday which followed two nights of deprivation the Ss were presented a serial list of trigrams in order to test whether prior deprivation had an effect on learning after deprivation.

The results of the deprivation effect on sleep indicated that although the Ss spent almost 8 hr. in bed, only 6 hr. were spent in EEG-defined sleep. Thus, all of the Ss were slightly sleep deprived in addition to the group who were REM deprived. There were an average of 11 awakenings per night for each S.

The results of the paired word task revealed no significant differences between conditions. The results of the serial learning task indicated no significant difference between the two groups in the number of correct anticipations on the tenth and final test trial and there were no differences in the serial position curve effect between groups. Even with a very liberal criterion of significance (a one-tailed t test, $p = .10$) there were no significant differences between groups

on any of the measures of learning of retention.

In this study the stage deprivation paradigm disrupted the Ss sleep on the average of 11 times per night. In addition, the Ss were also sleep deprived by approximately 2 hr. It should be noted that the effects of these awakenings and loss of sleep may affect the memory processes in many ways and the extent to which this occurs cannot be determined.

Only two studies employing the selective sleep stage deprivation paradigm have found a positive relationship between REM sleep and memory. The first study to find a memory deficit with lack of REM was performed by Adelman and Hartmann (1968). In an abstract of their study they reported that decrement on short-term memory for nonsense syllables was found on the morning following deprivation. REM deprivation was accomplished by means of amitriptyline which achieves almost total absence of REM sleep. However, this finding has not been replicated and it is difficult to determine whether the results may have been due to other aspects of the drug.

The second study to find a positive effect between REM and memory was performed by Empson and Clark (1970). They postulated that if REM sleep played a role in memory consolidation that REM induced organization of memory might show distortion or restructuring upon recall or provide a setting of the memory trace. Their Ss were EEG-monitored and spent the first of two nights adapting to the laboratory. On the second night the Ss and their yoked controls listened to a tape recording of a list of nouns, five nonsense sentences and a prose

passage. The experimental Ss were subsequently awakened whenever they showed signs of REM sleep while a yoked control was awakened at the same time but not in REM sleep.

During the night the REM deprived Ss had an average of 7 min. of REM while the control Ss averaged 46 min. of REM. In the morning the Ss were awakened and asked to recall in writing the materials they learned. The results indicated that the REM deprived group recalled significantly less of the sentences and of the prose passage than the nonREM deprived group. The REM deprived group was also significantly less accurate in their recall of the prose passage and had a significantly higher rate of distortion than the control Ss.

Empson and Clark hypothesized that REM sleep may play an important part in the consolidation of memories. There was, however, a significant difference in the overall amount of sleep between the two groups in that the REM group slept less and Empson and Clark correctly observed that the results could then be accounted for in terms of an interference theory of forgetting. As noted previously, the REM deprived group also had significantly more stage 4 than the control group. Consequently, it is impossible to determine whether lack of REM or increased amounts of stage 4 affected the recall.

It is also noteworthy that the control group in this study received an average of 46 min. of REM and, thus, was slightly REM deprived. It would be expected that an ideal yoked control group would receive from 72 to 80 min. of REM. This may attest to the deleterious aspects of the sleep stage depriva-

tion paradigm which requires numerous awakenings. In the
Ekstrand et al. study there were between 10 and 12 awakenings
per S and these occurred in addition to the first night effect
which also increases the amount of awakenings during sleep.
Since Ekstrand et al. employed their Ss for only one night,
both of these factors were operating to disrupt the normal
sleep. Evidence for this disruption in their study comes from
the report that the control Ss spent only 14 percent of their
sleep in REM in contrast with the normal 20-25 percent and the
stage 4 deprived Ss spent only 17 percent of their sleep in
REM. These disruptions and atypical sleep may possibly inter-
fere with the memory consolidation processes which are hypothe-
sized to occur during sleep and the use of the sleep stage
deprivation paradigm may deleteriously affect other aspects
of the processes under investigation.

In summary, the studies reviewed involving the sleep stage
deprivation paradigm have focused their attention upon the role
of REM sleep in memory. The weight of the evidence seems to
indicate that REM sleep is not involved or has a negative in-
fluence upon memory. It is important to note that the paradigm
itself may account for the variations in findings. Muzio
(1972) noted that any interference in the normal integrity of
uninterrupted sleep patterns may be associated with decreased
retention. Muzio found decreased retention for both REM de-
prived and nonREM deprived yoked controls and it appeared that
the commonality of the awakenings was the prime factor in re-
duced retention.

Investigations involving stage 4 as the source of the facilitating effect of sleep upon memory generally employ the paradigm where retention is measured over selected intervals of sleep which are known to contain differential amounts of stage 4 and REM sleep. Typically, this is accomplished by measuring retention over the first third of the night in which stage 4 sleep predominates and by measuring retention over the last third of the night in which REM sleep predominates. Yaroush, Sullivan and Ekstrand (1971) were the first investigators to utilize this distribution of stage 4 and REM during sleep in a selected sleep paradigm. In their experiment, Yaroush et al. measured retention of paired associate words over three conditions, (a) retention over the first half of sleep, (b) retention over the last half of sleep, and (c) retention over 4 hr. of wakefulness. The Ss in the first half condition learned the paired associates before sleep and were awakened 4 hr. later for testing. The Ss in the second half condition were awakened from sleep after 4 hr., learned the paired associates, slept 4 additional hr. and reawakened for testing. The Ss in the awake condition learned the paired associates in the morning, went about their normal activities and returned 4 hr. later for testing.

Retention was measured by paced recall, free recall, matching and relearning. The results indicated that memory was significantly better after the first 4 hr. of sleep than after the last 4 hr. of sleep or after the wakefulness condition. Since this latter finding was difficult to reconcile in light

of traditional interference theory, Yaroush et al. suggested
that sleep may influence memory in some other way than by
merely preventing retroactive inhibition due to interpolated
learning. Yaroush et al. hypothesized that sleep after learn-
ing facilitates recall because stage 4 sleep facilitates memory
consolidation and REM may interfere with consolidation. It
should also be noted that these effects on consolidation may
still occur in conjunction with the positive effect of sleep
due to its prevention of interpolated learning.

An important methodological consideration in the Yaroush
et al. study was the difference in time at which learning and
recall occurred for the experimental conditions. Learning and
retention may be differentially affected at different times in
the circadian rhythm and it might be expected that learning
which occurred after 4 hr. of previous sleep might be affected
differently than learning which occurred after 16 hr. of prior
wakefulness. In addition, Yaroush et al. did not employ EEG
monitoring so that the amounts of stage 4 and REM in the experi-
mental conditions could not be determined.

Fowler, Sullivan and Ekstrand (1973) reported a study
which controlled for the lack of EEG monitoring in the Yaroush
et al. experiment and took into account the prior wakefulness
of the first half condition Ss. In the first part of their
experiment, three groups of college students learned two memory
tasks: a verbal task which consisted of a list of paired
associates and a visual task consisting of "nonsense" shape
paired associates. The wakefulness group learned the material

during the day, were released from the laboratory for a 3 1/2 hr. retention interval filled with normal activity and returned for testing. The Ss in the two sleep conditions arrived at the lab in the evening, were prepared for monitoring and went to sleep. The Ss in the first half of the night condition were awakened after the first appearance of stage 2, learned the materials, slept an additional 3 1/2 hr. and were awakened for testing. The Ss in the second half condition were awakened for learning 4 hr. after the first appearance of stage 2, learned the materials, slept 3 1/2 hr. and were awakened for testing.

The results indicated that there was a significant sleep effect on memory for the verbal task but not the visual task. The first half Ss retained significantly more verbal paired associated than the second half Ss. The Ss in the awake condition retained significantly less than the other two conditions.

In the second part of the experiment, the task consisted of high and low imagery word pairs on the assumption that high imagery words are learned with the aid of visual-image mediators while low imagery pairs are learned by verbal mediators. The experimental conditions were the same. The results of this study revealed that high imagery words were forgotten significantly less than low imagery words and that significantly less was forgotten across both of these conditions for the first half Ss than the second half Ss. Again the second half Ss had forgotten significantly less than the Ss in the wakefulness condition.

Fowler et al. speculated that the results of their experiment suggested that REM sleep is not particularly beneficial to memory consolidation and that it appears that stage 4 is beneficial to memory. This is, of course, contrary to the earlier finding of Ekstrand et al. and the finding noted in the Empson and Clark study.

In the third of a series of studies Barrett and Ekstrand (1972) attempted to rectify the confounding of the sleep-awake variable with the time-of-day in the Yaroush et al. and Fowler et al. studies. The Ss in their experiment were college students who served in either a first half, second half, or awake condition. The retention interval was 4 hr. and occurred between 2:50 AM and 6:50 AM. The Ss in the first half condition went to bed at 2:00 AM and were awakened at 2:30 AM, if necessary and learned a list of paired associates. At 2:50 AM they went to sleep for 4 hr. and were awakened for recall at 6:50 AM. In the second half condition the Ss went to bed at 10:00 PM and were awakened at 2:30 AM for learning. The Ss returned to sleep for 4 hr. until they were awakened for testing at 6:50 AM. In the awake condition the Ss arrived at the laboratory at 10:00 PM and went to sleep. At 2:30 AM they were awakened, learned the list and remained awake until testing at 6:50 AM.

The results of both recall and recognitions tests revealed that memory over intervals of sleep was superior to memory over a period of wakefulness. Between the two sleep intervals first half Ss showed significantly less forgetting than the

second half $\underline{S}$s. This finding supports the work of Yaroush et al. and Fowler et al. and indicates that differential retention over sleep intervals cannot be accounted for in terms of interference theory. The results imply that either stage 4 sleep facilitates memory or REM sleep inhibits memory or that both processes are operative.

Additional evidence that stage 4 facilitates memory comes from the study of Hockey, Davies and Gray (1972). College students learned 30 common nouns and the retention measure was written free recall. Two night groups learned at 11:00 PM and recalled at 4:00 AM. After initial learning the Night Sleep $\underline{S}$s went to sleep and the Night Awake $\underline{S}$s stayed awake reading, talking or playing games. The morning groups were awakened from their normal sleep and learned at 6:30 AM and tested at 11:30 AM. After learning the Morning Sleep $\underline{S}$s returned to sleep and the Morning Awake $\underline{S}$s carried on their normal activities.

The results indicated that the night conditions had significantly better retention than the morning conditions, regardless of whether the $\underline{S}$s were asleep or awake. It also appeared that sleep during the evening was slightly more efficacious to memory than wakefulness during the evening, however, sleep did not favor memory in the morning conditions.

The findings of Hockey et al. demonstrate the inadequacy of an interference theory of forgetting and reveal the serious confounding of the sleep-awake variable with time of day which exists in the studies (Jenkins & Dallenbach, 1924; Van Ormer,

1932) which interpreted the facilitating effect of sleep in interference theory terms. The memory of the sleep Ss in these studies was tested after intervals of night sleep, which should favor memory regardless of sleep, while Ss in the wakefulness condition were tested during the daytime, which should have a depressing influence on memory. In addition, the Hockey et al. findings implicate stage 4 as a possible source of the facilitating effects of sleep upon memory and the possibility that REM may interfere with memory. However, it should be noted that there was no significant difference in retention between the Night Sleep and Night Awake Ss in the Hockey et al. study, although a trend in favor of the memory of the Night Sleep Ss was evident.

There are, however, alternative explanations. For example, stage 4 sleep may facilitate the recall of memories to be consolidated and this could account for the poor retention of the morning conditions. An additional problem with the Hockey et al. paradigm was that the morning sleep Ss had an initial 5 hr. of sleep and 5 additional hr. of sleep in the morning retention interval. For these Ss recall would have occurred after approximately 10 hr. of sleep. Taub, Globus, Phoebus and Drury (1971) have noted deleterious effects upon performance of extended intervals of sleep and recall of the morning sleep Ss may have suffered as a result of this performance decrement.

In summary, the studies reviewed concerning memory over selected sleep intervals have implicated stage 4 as beneficial

to memory consolidation and REM sleep as deleterious to consolidation. It is important to note, however, that a confounding in these studies has been the comparison of memory at different times in the circadian rhythm. Even when time-of-day is controlled, as in the Barrett and Ekstrand study, the placement of sleep in the 24 hr. cycle is a critical variable. Barrett and Ekstrand allowed for 4 hr. of prior sleep in two conditions and 18 hr. of prior wakefulness in the other condition. It seems highly probable that memory may vary as a function of those conditions. Unfortunately, unraveling the time-of-day and circadian confoundings appears to be an exceedingly complex task.

Time of Day and Arousal Effects on Memory. There is ample evidence to indicate that memory varies diurnally. Studies on short-term memory (STM) have indicated that STM is better in the morning and declines steadily throughout the day (Freeman & Hovland, 1934; Blake, 1967; Baddeley, Hatter, Scott & Snashall, 1970). In contrast, long-term memory (LTM) appears to be better over evening retention intervals than over comparable morning retention intervals (Hockey, Davies & Gray, 1972).

Ebbinghaus (1885) first noted a time-of-day effect on memory. He found that serial lists of nonsense syllables were learned more efficiently in the morning and he assumed that the effect was caused by the decline of mental vigour and receptivity throughout the day. Freeman & Hovland (1934) cited the works of Schuyten (1903), Pillsbury (1903), Marsh (1906) and Winch (1912), all of whom found either better immediate memorizing

attention capacity or learning in the morning compared to the evening. Blake (1967) tested a number of performance tasks including digit span at five different times during the day ranging from 8:00 AM to 9:00 PM. In general, Blake found that there was a definite diurnal variation in performance with efficiency improving throughout the day, with the exception of digit span which tended to deteriorate significantly throughout the day. Blake interpreted this diurnal variation as related to underlying states of arousal as indicated by body temperature which is known to drop to a low level during sleep at night and rise during the day to a peak at midevening. Accordingly, learning should be better when body temperature is lower and thus be most efficient during the night and early morning, although evidence indicates that performance on a number of measures is generally poorer when body temperature is lower (Colquhoun, 1972).

Baddeley, Hatter, Scott and Snashall (1970) tested the immediate recall of Ss for sequences of digits in the morning and in the afternoon. They found significantly better immediate recall in the morning than in the afternoon and attributed the effect to a circadian fluctuation in level of arousal.

In other studies diurnal variations in memory were incidental findings. Jenkins and Dallenbach noted that one S averaged one more repetition at night than during the day and their other S averaged two more repetitions at night than during the day, but stated that these differences were too small to be significant. However, if it is taken into account that Jenkins and Dallenbach's experiment continued day and night for

almost two months, it is tempting to conclude that they have documented rather well a diurnal variation in memory.

Van Ormer also noted a diurnal variation in that he found morning and afternoon sessions to be superior to late evening learning. Newman (1939) found slightly better retention over a morning period of wakefulness compared to an afternoon retention interval of wakefulness, although there was no immediate test of memory and as such the retention may have reflected differences in original learning. Finally, Lovatt and Warr (1968) noted superior learning in the morning learning sessions compared to the afternoon.

The variation in memory capability can be explained by a modified arousal-perseveration consolidation theory of memory. One of the first studies to present evidence that arousal can affect reverberatory consolidation activity was presented by Pare (1961) when he found that rats injected with a depressant during the retention interval made more errors compared to controls on subsequent testing. Injection of a stimulant decreased errors. This suggested that consolidation can be either facilitated or impaired by an acceleration or deceleration of the stimulus trace. Additional support for arousal effects on consolidation comes from the work of Kleinsmith and Kaplan (1963). Using college students as $\underline{S}$s, they found that $\underline{S}$s who learned paired-associates under low levels of arousal (as measured by GSR) exhibited better STM and poorer LTM while $\underline{S}$s who learned paired-associates under high levels of arousal exhibited poor STM and better LTM. They postulated that the greater the level of arousal, the greater the number of times

the trace would reverberate, and the greater the perseveration consolidation of the trace, the stronger the permanent memory. However, the perseveration process under high levels of arousal indicates that the neurons are already firing or are in an absolute or relative refractory state and consequently, the trace remains unavailable for immediate recall. Kleinsmith and Kaplan (1964) replicated their earlier study and demonstrated that the phenomenon was independent of the association values of the words.

Walker and Tarte (1963) hypothesized two important functions of the perseverative consolidation process: (a) permanent memory is laid down during this active phase in a gradual fachion, and (b) during the active period, there is a degree of temporary inhibition of recall which serves to protect the consolidating trace from disruption. They also noted that high arousal during the associative process will result in a more intense active trace process which results in greater long-term memory, however, at the expense of greater temporary inhibition for immediate recall.

In their study nine groups of Ss learned either a list of words which elicited high arousal as measured by GSR, a low arousal list or a mixed arousal list. One group recalled the list after 2 min., one after 45 min., and one after 1 week. The low arousal list was recalled well immediately and recall decreased with time. The high arousal list was recalled increasingly better with time. The authors reported that other analyses agreed with the results of Kleinsmith and Kaplan (1964)

which showed high immediate and low ultimate recall for items of low arousal and low immediate recall and high ultimate recall for items learned under high arousal.

Lavach (1973) corroborated these findings when he presented Ss a taped lecture with arousing words preceding selected passages. He found that a S under low arousal when tested immediately remembered three times as much information as a S under high arousal. After 30 days, however, a S under high arousal remembered twice as much as a S under low arousal.

Kleitman (1963) has noted that the level of physiological arousal in man tends to increase as the day progresses and, therefore, it may be assumed under the arousal-perseveration consolidation theory of memory STM should be better in the morning and decline steadily. In contrast, LTM should be more efficient during the evening and less efficient during the morning.

It is important to note that the studies by Pare, Kleinsmith and Kaplan, Walker and Tarte and Lavach observed memory effects as a function of temporary shifts in basal level of arousal. It is possible that natural diurnal shifts in arousal may have a different effect on memory or have no effect whatsoever. In addition, the concept of level of arousal is only inferred from a myriad of underlying physiological processes. It may be that the memory effect is better explained by relating it to some other process or processes such as metabolic rate.

In summary, the implications of the studies reviewed are

important for two reasons. First, they show a diurnal varia-
tion in memory which should be viewed as a potential variable
in any memory experiment. Second, it appears that memory
varies as a function of some physiological process which may
be differentially affected by qualitatively different aspects
of sleep. This process should be given consideration in the
development of a general theory of memory.

The purpose of the present experiment was to compare
memory over intervals of sleep with memory over intervals
of wakefulness, when the intervals in these conditions occur
at the same time of day. Measures of both short- and long-
term memory were taken to investigate their relationship to
man's diurnal rhythm and to test an arousal-perseveration
consolidation theory of memory. The effects of the interaction
between memory and stages of sleep were also examined.

It is hypothesized that memory varies diurnally, specifi-
cally, (a) STM is better in the morning and decreases in
efficiency in the evening, (b) LTM is better in the evening
and is less efficient during the day, and (c) the time-of-day
variable is a stronger factor in forgetting than the sleep-
awake variable. Finally, it is predicted that stage 4 and REM
sleep differentially affect ongoing consolidation of memory:
REM sleep occurring in the retention interval is detrimental
to LTM while stage 4 in the retention interval favors retention.

CHAPTER II
METHOD

Overview. Short- and long-term memory were tested in
five time periods: 8:30 AM to 11:30AM; 11:30 AM to 2:30 PM;
2:30 PM to 5:30 PM; 5:30 PM to 8:30 PM; and 8:30 PM to 11:30
PM. Twenty Ss were assigned to each time period and during
the LTM retention interval of 2 hr., half of the Ss remained
awake and half slept.

Subjects. The Ss were 123 college student volunteers
(ages 18-25) from an introductory psychology course at the
University of Florida. In order to control for prior sleep
effects, the Ss were encouraged to maintain their normal sleep
schedule, to refrain from drugs and alcoholic or caffeinated
beverages and to awaken by 8:00 AM on the day of the experi-
ment.

For the Ss in the sleep conditions, the following sleep
criterion was established: a sleep onset of less than 50 min.
and more than 50 min. of sleep in the 120 min. interval.
Eighteen Ss failed to reach criterion, two Ss had severe arti-
facts in their EEG records and three Ss reported rehearsing
the memory task during the retention interval. Thus, 23 Ss
of a total of 123 Ss were eliminated from statistical analysis,
which resulted in an equal number of Ss (10) in each Time
Period x Sleep-Wakefulness combination.

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Apparatus. A Grass Model VI EEG monitored the $\underline{Ss}$'
sleep. The $\underline{Ss}$ were wired according to the international 10-20
system and EEG recordings were obtained between F_1 and F_7, and
O_3 and O_zP_z. Electrodes placed laterally from the outer can-
thus of the left eye to a supraorbital site above the left eye
detected electrooculogram activity.

Procedure. The $\underline{Ss}$ in all conditions were wired for EEG
and EOG recordings, although only the $\underline{Ss}$ in the sleep condi-
tions were monitored. Learning and recall were identical for
all conditions. At the beginning of each condition, the $\underline{Ss}$
were presented a list of 16 common, concrete nouns obtained
from a series of lists prepared by Underwood (1966, see
Appendix A). The $\underline{E}$ pronounced and spelled each word and the
$\underline{Ss}$ recorded each word on paper. Immediately after the words
were presented and the written list removed, the $\underline{Ss}$ were in-
structed to write down as many words as possible in any order.
This test served as the verbal STM measure.

After recall the $\underline{Ss}$ were told that the $\underline{E}$ would again pro-
nounce and spell each word and the $\underline{Ss}$ would record each word
on paper with the exception that they were to place a check by
the words they were able to successfully recall. They were
instructed that this test would serve as a final test of STM,
although in actuality the $\underline{Ss}$ were tested again after 2 hr.
This procedure was performed to reduce the chance of rehearsal
during the remainder of the session. Three $\underline{Ss}$ were eliminated
from analysis when they revealed during debriefing that they
suspected they would be tested again and actively rehearsed
the words.

After the verbal learning tests, the Ss were presented
a series of 20 passport-type faces by means of a carousel
slide projector at the rate of 1 per s. The Ss were instructed
to memorize the faces carefully. After presentation the Ss
were given a multiple choice test which consisted of a series
of 20 slides containing four faces each, only one of which the
S had seen before. The Ss were allowed 10 s. for each trial.
After this test which served as a measure of visual STM, the
Ss were given a second series of 20 novel faces and were told
they would be tested for their recognition of these faces in
2 hr. The test after 2 hr. served as a measure of visual
LTM.

Four Ss participated simultaneously in most cases during
an experimental session. The Ss were assigned to the sleep
and wakefulness conditions on the basis of their scores on
the verbal STM test. The best and worst learners were alter-
nately assigned to the sleep and wakefulness conditions
throughout the experiment. This procedure insured that any
differences in long-term memory would be less likely due to
initial learning capabilities of the Ss. After the STM tests
the Ss were placed in separate rooms, which contained a bed
for the Ss in the sleep conditions and a table and chair for
the Ss in the wakefulness conditions. The Ss in the sleep
condition went to bed and were told to relax and sleep. The
Ss in the wakefulness conditions were given a jigsaw puzzle
and a deck of cards to occupy their time. At the end of the
2 hr. period, all of the Ss left their rooms and returned to

the testing rooms where they were given a sheet of paper and asked to recall as many words as possible in any order. Immediately afterwards, the $\underline{S}$s were tested for their recognition of the second set of pictures.

CHAPTER III
RESULTS

Sleep stage characteristics. The sleep stage character-
istics of the five time periods were compared using a one-
factor completely randomized multivariate analysis of variance
of seven dependent variables: total amount in minutes of
stages 0, 1, 2, 3, 4, REM and the number of minutes until
sleep onset. The mean total minutes for each dependent
variable for each time period is presented in Table 1.

The hypothesis that the five sleep conditions were equal
with respect to the dependent variables was rejected at p <.005
(F = 2.13, df = 28 and 142). Multivariate post hoc examina-
tions revealed that the 8:30 AM-11:30 AM time period differed
significantly on the dependent variables from the 2:30 PM-
5:30 PM, 5:30 PM-8:30 PM and the 8:30 PM-11:30 PM time periods.
A summary of these analyses is presented in Table 2.

Examinations of the individual dependent variables as a
function of the time periods revealed that there were no sig-
nificant differences between the conditions on the total amount
in minutes of stage 0, 2 or to sleep onset. The Ss in the 8:30
AM-11:30 AM period received significantly more REM sleep than
the other four time periods and they had significantly less
stage 4 than the 2:30 PM, 5:30 PM or 8:30 PM conditions. The
11:30 AM condition had significantly less stage 4 than the

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Table 1

Mean Total of Minutes of Stages of Sleep and Sleep Onset as
a Function of Time Periods

Stages	0	1	2	3	4	REM	Onset
Time							
8:30 AM	32.8	16.6	39.4	1.9	6.3	22.3	19.7
11:30 AM	33.6	17.5	40.8	3.4	13.3	10.6	21.7
2:30 PM	29.5	20.4	31.5	3.9	22.0	11.0	15.5
5:30 PM	29.8	9.3	39.5	5.4	30.9	4.1	16.3
8:30 PM	27.2	15.9	35.5	3.6	32.7	3.2	11.3
	(17.8)	(10.7)	(12.5)	(2.7)	(13.5)	(10.8)	(11.3)

Note: There were 10 $\underline{S}$s in each time period. Standard
deviations are given in parentheses.

Table 2

Multivariate Comparisons between Time Periods on
Seven Dependent Variables: Stages 0, 1, 2, 3, 4,
REM and Sleep Onset

	8:30 AM	11:30 AM	2:30 PM	5:30 PM	8:30 PM
8:30 AM	—	nonsig.	p <.05	p <.001	p <.001
11:30 AM	—	—	nonsig.	p <.06	p <.05
2:30 PM	—	—	—	nonsig.	nonsig.
5:30 PM	—	—	—	—	nonsig.
8:30 PM	—	—	—	—	—

5:30 PM and 8:30 PM conditions. A summary of the univariate examinations is presented in Tables 3 through 9.

Short-term memory. The STM data were analyzed by means of a one-factor multivariate analysis of variance performed upon the total number of words correctly recalled on the verbal STM test and upon the total number of pictures correctly recognized on the visual STM test. The dependent variables were analyzed as a function of the five time periods across both sleep and wakefulness conditions.

Contrary to expectations, the analysis revealed no significant differences between conditions in STM ($\underline{F}$ = .59, $\underline{df}$ = 8 and 188). The means for each dependent variable as a function of time periods are presented in Table 10.

The STM data were also analyzed for the serial position effect. Glanzer and Cunitz (1966) have noted that items in a list may be processed by two component mechanisms. The latter items may be processed through primary (short-term) memory while the early items may be transferred to LTM. For the verbal data a ratio was formed for each $\underline{S}$ between the number of correct words which occurred in the first half of the list and the second half. For the visual data ratios were also formed for each $\underline{S}$ between the number of correct pictures recognized in the first half of the series and the second half. The ratios were analyzed by means of a one-factor completely randomized multivariate analysis of variance. The dependent variables were examined to determine changes as a

Table 3

Univariate Comparisons in Minutes of Stage 0 as a
Function of Time Periods
(with minutes of Stage 0 in parentheses)

	8:30 AM (32.8)	11:30 AM (33.6)	2:30 PM (29.5)	5:30 PM (29.8)	8:30 PM (27.2)
8:30 AM	–	nonsig.	nonsig.	nonsig.	nonsig.
11:30 AM	–	–	nonsig.	nonsig.	nonsig.
2:30 PM	–	–	–	nonsig.	nonsig.
5:30 PM	–	–	–	–	nonsig.
8:30 PM	–	–	–	–	–

Table 4

Univariate Comparisons in Minutes of Stage 1 as a
Function of Time Periods
(with minutes of stage 1 in parentheses)

	8:30 AM (16.6)	11:30 AM (17.5)	2:30 PM (20.4)	5:30 PM (9.3)	8:30 PM (15.9)
8:30 AM	−	nonsig.	nonsig.	nonsig.	nonsig.
11:30 AM	−	−	nonsig.	nonsig.	nonsig.
2:30 PM	−	−	−	$p < .05$	nonsig.
5:30 PM	−	−	−	−	nonsig.
8:30 PM	−	−	−	−	−

Table 5

Univariate Comparisons in Minutes of Stage 2 as a
Function of Time Periods
(with minutes of Stage 2 in parentheses)

	8:30 AM (39.4)	11:30 AM (40.8)	2:30 PM (31.5)	5:30 PM (39.5)	8:30 PM (35.5)
8:30 AM	–	nonsig.	nonsig.	nonsig.	nonsig.
11:30 AM	–	–	nonsig.	nonsig.	nonsig.
2:30 PM	–	–	–	nonsig.	nonsig.
5:30 PM	–	–	–	–	nonsig.
8:30 PM	–	–	–	–	–

Table 6

Univariate Comparisons in Minutes of Stage 3 as a
Function of Time Periods
(with minutes of Stage 3 in parentheses)

	8:30 AM (1.9)	11:30 AM (3.4)	2:30 PM (3.9)	5:30 PM (5.4)	8:30 PM (3.6)
8:30 AM	–	nonsig.	nonsig.	p <.01	nonsig.
11:30 AM	–	–	nonsig.	nonsig.	nonsig.
2:30 PM	–	–	–	nonsig.	nonsig.
5:30 PM	–	–	–	–	nonsig.
8:30 PM	–	–	–	–	–

Table 7

Univariate Comparisons in Minutes of Stage 4 as a
Function of Time Periods
(with minutes of Stage 4 in parentheses)

	8:30 AM (6.3)	11:30 AM (13.3)	2:30 PM (22.0)	5:30 PM (30.9)	8:30 PM (32.7)
8:30 AM	−	nonsig.	p <.025	p <.001	p <.001
11:30 AM	−	−	nonsig.	p <.01	p <.005
2:30 PM	−	−	−	nonsig.	nonsig.
5:30 PM	−	−	−	−	nonsig.
8:30 PM	−	−	−	−	−

Table 8

Univariate Comparisons in Minutes of REM Sleep as a
Function of Time Periods
(with minutes of REM Sleep in parentheses)

	8:30 AM (22.3)	11:30 AM (10.6)	2:30 PM (11.0)	5:30 PM (4.1)	8:30 PM (3.2)
8:30 AM	–	p <.025	p <.025	p < .001	p < .001
11:30 AM	–	–	nonsig.	nonsig.	nonsig.
2:30 PM	–	–	–	nonsig.	nonsig.
5:30 PM	–	–	–	–	nonsig.
8:30 PM	–	–	–	–	–

Table 9

Univariate Comparisons in Minutes Until Sleep Onset
as a Function of Time Periods
(with Sleep Onset in parentheses)

	8:30 AM (19.7)	11:30 AM (21.7)	2:30 PM (15.5)	5:30 PM (16.3)	8:30 PM (11.3)
8:30 AM	–	nonsig.	nonsig.	nonsig.	nonsig.
11:30 AM	–	–	nonsig.	nonsig.	nonsig.
2:30 PM	–	–	–	nonsig.	nonsig.
5:30 PM	–	–	–	–	nonsig.
8:30 PM	–	–	–	–	–

Table 10

Mean Number of Correct Words Recalled for Verbal Short-Term
Memory and the Mean Number of Correct Pictures Recognized for
Visual Short-Term Memory as a Function of Time Periods

	8:30 AM	11:30 AM	2:30 PM	5:30 PM	8:30 PM
Short-Term Memory Verbal	10.40 (2.0)	11.10 (2.1)	11.55 (1.9)	11.10 (2.6)	11.30 (1.9)
Short-Term Memory Visual	13.75 (3.0)	13.75 (1.9)	14.65 (3.6)	14.35 (2.6)	14.50 (2.4)

Note: There were 20 Ss in each time period who were tested
on both short-term verbal and visual memory. Standard
deviations are given in parentheses.

function of the five time periods. The hypothesis that the time periods were equal with respect to the STM ratios was not rejected (F = 1.15, df = 8 and 188). Post hoc examinations revealed that the highest value of the ratio (primacy effect) for verbal STM occurred in the 8:30 AM time period and the lowest value (recency effect) occurred in the latest time period. These means, however, were not significantly different (F = 2.59, df = 1 and 95, p <.12). For the visual STM ratios, there was a significant difference between the 2:30 PM-5:30 PM condition and the two earlier time periods. The earliest time period had a significantly higher ratio than the 2:30 PM condition (F = 4.42, df = 1 and 95, p <.05) and the ratio for the 11:30 AM-2:30 PM condition was significantly higher than the 2:30 PM condition (F = 3.93, df = 1 and 95, p <.06). The ratios are presented in Appendix B.

The STM component was further examined in (a) analyses of variance of the differences between the time periods on the total number of correct responses for the second-half of the verbal and visual STM tests and (b) analyses of covariance of the differences between the time periods on total correct in the second-half for verbal and visual STM while the total number of correct for both halves was covaried.

For verbal STM, the lowest second-half mean recall occurred in the earliest time period while the highest mean recall occurred in the latest time period. These scores may reflect an increase in either capacity or efficiency of STM as a function of time-of-day. The differences between the

earliest and latest time periods were significant at $p < .07$
(mean for 8:30 AM = 4.55 words correct, mean for 8:30 PM =
5.40 words correct). However, when the total number of correct
for both halves was covaried, these differences were no longer
significant ($F = 1.52$, $df = 1$ and 94) which may indicate the
differences occurred as a function of changes in the LTM
component in the STM task.

Analysis of the visual STM second-half scores may not be
as easily interpreted. It has been suggested that the modality
of the STM system is primarily acoustical (Kausler, 1974),
although it may merely reflect a subject preference to operate
in this modality (Laughery & Fell,1969). Nevertheless, Madigan
(1971) has shown that in accordance with an aural encoding
hypothesis, the characteristic serial position effect is dif-
ferent for auditory and visual presentation in that visual stim-
uli do not show as great a recency effect as aural stimuli.
For the visual STM scores, there was a significant difference
between the recall in the two earliest time periods and recall
in the 2:30 PM time period (mean pictures recognized for 8:30
AM = 5.75, mean for 11:30 AM = 5.75, mean for 2:30 PM = 7.05;
$F = 4.61$ and $F = 4.61$, $df = 1$ and 95, $p < .05$). When the total
amount correct was covaried, the results remained essentially
the same. For visual STM, these data substantiate a rise in
STM capacity or efficiency although the maximum rise occurred
earlier for visual than for verbal STM.

Long-term memory: Sleep conditions. In order to deter-
mine whether individual sleep stages had an effect on LTM, a

one-factor completely randomized multivariate analysis of covariance was performed on verbal LTM recall and on visual LTM recognition. There were seven covariates: verbal STM scores, visual STM scores, the number of minutes of stages 0, 4, REM, the number of minutes until sleep onset and the number of minutes of prior wakefulness for each $\underline{S}$. The dependent variables were analyzed as a function of the five time periods.

A test of the covariates' effects on the dependent variables revealed that verbal STM had a significant effect ($\underline{F}$ = 15.34, $\underline{df}$ = 2 and 37) at $\underline{p} < .001$ and visual STM had a significant, though less powerful effect at $\underline{p} < .05$. Stages 0, 4, REM, sleep onset and prior wakefulness did not significantly influence the dependent variables.

The hypothesis that LTM was equal across the five time periods was not rejected ($\underline{F}$ = 1.22, $\underline{df}$ = 8 and 74, $\underline{p} < .25$). Multivariate post hoc examinations between the time periods revealed that LTM differed significantly for the 5:30 PM-8:30 PM and for the 8:30 PM-11:30 PM time periods. A univariate post hoc examination of this difference revealed that verbal LTM accounted for this significant effect ($\underline{F}$ = 8.65, $\underline{df}$ = 1 and 38, $\underline{p} < .01$). The mean number of words recalled for the 5:30 PM condition was 11.4 and the mean for the 8:30 PM condition was 12.9 (regressed mean values = 4.9 and 8.3, respectively).

Long-term memory: Awake conditions. For LTM in the awake conditions, a one-factor completely randomized multivariate analysis of covariance was performed on verbal LTM

recall and on visual LTM recognition. The covariates employed
were the STM, verbal and visual scores, and the number of
minutes of prior wakefulness for each $\underline{S}$. The dependent vari-
ables were analyzed as a function of the five time period
conditions.

Analysis of the covariates revealed that verbal STM
significantly affected the dependent variables ($\underline{F}$ = 9.70,
$\underline{df}$ = 2 and 41) at $\underline{p}$ <.001, and visual STM exerted a signifi-
cant effect ($\underline{F}$ = 9.85, $\underline{df}$ = 2 and 41) at $\underline{p}$ <.001. The amount
of prior wakefulness did not significantly affect the depen-
dent variables ($\underline{F}$ = .43, $\underline{df}$ = 2 and 41).

The hypothesis that the time conditions were equal with
respect to the LTM variables was not rejected ($\underline{F}$ = .38, $\underline{df}$ =
8 and 82). Post hoc examinations revealed no significant
differences between any of the time conditions on either ver-
bal or visual LTM.

Long-term memory: Time-of-day and sleep-wakefulness. A
two-factor completely randomized multivariate analysis of co-
variance was performed on the verbal LTM recall and on the
visual LTM recognition. The covariates were the scores on the
verbal STM test and the visual STM test. The dependent vari-
ables were analyzed as a function of the five time periods
and as a function of the sleep and wakefulness conditions. The
means for this analysis are presented in Table 11.

Both covariates affected long-term memory significantly
at $\underline{p}$ <.001 (verbal STM covariate, $\underline{F}$ = 24.77, $\underline{df}$ = 2 and 87;
visual STM covariate, $\underline{F}$ = 15.01, $\underline{df}$ = 2 and 87). In the multi-
variate test, the main effects of the sleep-wakefulness vari-

Table 11

Mean Number of Correct Words Recalled for Verbal Long-Term
Memory and the Mean Number of Correct Pictures Recognized
for Visual Long-Term Memory as a Function of Time-of-Day and
Sleep-Wakefulness Conditions

		8:30 AM	11:30 AM	2:30 PM	5:30 PM	8:30 PM
Long-Term Verbal Memory	Sleep	11.0 (2.5)	13.1 (1.7)	12.5 (2.3)	10.4 (3.0)	13.8 (1.5)
	Awake	12.0 (2.2)	12.1 (2.2)	13.2 (1.6)	13.1 (1.2)	11.6 (2.5)
Long-Term Visual Memory	Sleep	10.2 (2.2)	12.1 (2.5)	11.8 (3.6)	11.4 (3.4)	12.9 (2.7)
	Awake	10.4 (1.8)	9.6 (3.9)	12.7 (4.8)	11.6 (3.7)	10.3 (3.7)

Note: Standard deviations are given in parentheses.

able (F = 1.06, df = 2 and 87), time-of-day (F = .68, df = 8 and 174), and the interaction between sleep-wakefulness and time-of-day were nonsignificant (F = .84, df = 8 and 174). A univariate analysis of covariance performed upon the verbal LTM scores revealed no sleep-wakefulness effect (F = .66, df = 1 and 88), no time-of-day effect (F = 1.02, df = 4 and 88) and no significant interaction between sleep-wakefulness and time-of-day (F = 1.31, df = 4 and 88). A univariate analysis of covariance on the visual LTM scores revealed no significant main effects or interaction (sleep-wakefulness, F = 1.61, df = 1 and 88; time-of-day, F = .34, df = 4 and 88; interaction, F = .35, df = 4 and 88).

Long-term memory was also analyzed as a function of the percentage of loss or gain in memory from the short-term to the long-term testing. This procedure was similar to that used by Hockey, Davies and Gray (1972). A two-factor multivariate analysis of variance was performed upon the percentage of loss or gain on both verbal and visual LTM. This percentage was obtained by subtracting the STM score from the LTM score and dividing by the STM score. The percentages were examined as a function of the sleep-wakefulness conditions and time-of-day. The analyses revealed no significant main effects or interaction effects for the multivariate or univariate comparisons. For verbal memory, there was an 11 percent increase for the sleep condition and a 14 percent increase for the wakefulness condition (F = .48, df = 1 and 90). For visual memory there was a 17 percent loss for the sleep condition and a 22

percent loss for the wakefulness condition ($F = 1.64$, $df = 1$ and 90). There were no apparent trends as a function of time-of-day for either verbal or visual memory (verbal, $F = .37$, $df = 4$ and 90; visual, $F = .36$, $df = 4$ and 90).

The percentages of loss or gain were also examined with a multivariate analysis of covariance in order to control for any differences in the total number of correct responses between time periods. This analysis revealed that the covariate of total amount correct for visual memory significantly affected the percentage of loss or gain ($F = 4.37$, $df = 2$ and 87, $p < .025$). Overall there were, however, no significant main effects or interaction effects for the multivariate or separate univariate comparisons.

CHAPTER IV
DISCUSSION

Short-term memory and time-of-day. There were no
significant memory variations as a function of time periods
in the total amount learned for either verbal or visual STM.
There were, however, significant changes in visual STM "ratios"
in the first three time periods (8:30 AM, 11:30 AM, 2:30 PM).
The ratios were obtained by dividing the number correct in the
first half of a series by the second half. These may reflect
the relative weights of primary and secondary memory process-
ing in the series. A large ratio value (greater than 1) may
reflect heavier secondary or LTM processing while values less
than 1 may reflect greater primary or short-term processing.
In this study the largest verbal STM ratio occurred in the
earliest time period and the smallest ratio was obtained
during the latest time period (8:30 PM), although these dif-
ferences were not significant ($p < .12$). For visual STM the
largest ratio was again obtained in the earliest time period
and was significantly larger than the ratio for the 2:30 PM
time period ($p < .05$). These changes in the ratios may be
interpreted in two ways. First, LTM may become less efficient
as the time awake increases or STM may become more efficient
with time-of-day. Analyses of the number correct in the
second-half of the verbal STM test revealed that the latter may

be the case. The 8:30 PM condition was associated with the highest mean recall while the 8:30 AM condition had the lowest mean recall (p <.07). This finding is consistent with the evidence that performance on a number of measures tends to increase during the day (Kleitman, 1963; Colquhoun, 1972). However, the finding is in stark contrast to the hypothesis that STM is negatively correlated with time-of-day (Blake, 1967; Baddeley et al., 1970).

It is possible that the STM task in this study may have been confounded because the task still contained a LTM component. The Blake and Baddeley et al. studies employed digit span as the STM task, which may account for the differences in findings. It is also interesting to speculate that the STM variations in the Blake and Baddeley et al. studies may have occurred as a function of a change in STM capacity. It may be that the present study examined an efficiency parameter of memory rather than capacity. The capacity of STM, in the present context, refers to the increase or decrease in the memory trace decay rate (Hamilton, Wilkinson & Edwards, 1972). If the decay rate is increased, then the capacity of STM is reduced while if decay rate is decreased, capacity is increased. Efficiency refers to the $\underline{S}$s' compensatory behavior as a result of the changes in short-term memory processing, e.g., strategies or increased motivation which may develop as a result of these changes.

Long-term memory and time-of-day. For the Ss in the Awake condition, analyses revealed no significant changes in either long-term verbal or visual memory as a function of time-of-day. One critical test for time-of-day effects was the test of the relationship between the covariate, amount of prior wakefulness, and the dependent variables. Because the Ss' awaking time (8:00 AM) was relatively constant and only the testing time varied (8:30 AM, 11:30 AM, 2:30 PM, 5:30 PM, 8:30 PM), the effect of time-of-day on LTM might have been reflected in the wakefulness covariate. However, the covariate had no significant effect on memory ($p < .25$).

Long-term memory and sleep-wakefulness. Differences in sleep stage characteristics between time periods were clearly established. The Ss in the early sleep condition received significantly more REM sleep than the Ss in the later time periods, and the Ss in the three latest time periods received significantly more stage 4 than the earliest time condition. However, the hypothesis that LTM was equal across the five time periods could not be rejected. The implication of this finding is relatively clear. Even though differences in theoretically important stages of sleep (4 and REM) were reliably established, LTM was unaffected.

The finding that sleep may have little or no effect on memory is not without support. Chernik (1972) found no substantial effect of two days of REM sleep deprivation on serial learning or paired-associate retention. Ekstrand, Sullivan, Parker and West (1971) found no effects of one night of either

stage 4 or REM deprivation on any of four measures of reten-
tion. Feldman (1970) reported a LTM decrement after a single
night of REM deprivation but in a subsequent experiment
employing two nights of REM deprivation he failed to replicate
the effect. Finally, the finding by Empson and Clark (1971)
that REM decreases retention may have occurred as the result
of a paradigm artifact. Muzio (1972) has noted that decreased
retention in the specific sleep stage paradigm can occur as
the result of numerous awakenings and not as the result of the
loss of REM sleep.

It is also possible that a majority of the studies which
purported to investigate the effects of sleep on LTM consoli-
dation employed inadequate paradigms (Yaroush, Sullivan & Ek-
strand, 1971; Barrett & Ekstrand, 1972; Fowler, Sullivan &
Ekstrand, 1973). It is compelling to speculate that the
long-term consolidation processes may be of relatively short
duration. Evolutionarily, it would have been adaptive for
an organism to develop a process to recall information at a
later period of time. However, if the process of information
storage was excessively lengthy then new information might
interfere with the old information, or new information would
not be encoded due to the lengthy processing time. The resul-
tant length of the consolidation process might have been a
function of at least two properties. First, the process should
continue long enough for the information to be recalled adequate-
ly, and the process must be such that new information could be
constantly acquired. Spevack and Suboski (1969) have argued

in favor of a consolidation process which is completed within a period of a few seconds. Walker (1958) presented evidence that only a small percentage of the perseveration process is completed in the first 10 seconds and that a majority of the perseveration process is completed within 15 minutes. If the process is complete within a period of seconds or minutes then many experimental paradigms are not relevant as a test of the effects of sleep on consolidation. In the present study the average sleep onset time was approximately 17 min. and it appears that by that time either all or a majority of the perseverative consolidation may have occurred. Thus, sleep or wakefulness in the retention interval should have a minimal effect on consolidation.

If the experimental paradigms are inappropriate to test the hypothesis that sleep facilitates memory consolidation, then how can the findings of better recall after sleep be accounted for? One plausible alternative is that sleep may facilitate subsequent recall by acting favorably on the established memory trace,e.g., reducing retroactive inter- ference. In this respect,the longer the interval of sleep, the greater the protection afforded the neural trace. The present studies' use of 2 hr. intervals of sleep may not have been sufficient in length to demonstrate a difference in for- getting between sleep and waking intervals. Van Ormer (1932) found no clear advantage of sleep over wakefulness at 1 or 2 hr. intervals, although Jenkins and Dallenbach did demon- strate the effect with 2 hr. intervals.

A second hypothesis is that the findings may be arti-
factual and arise from the experimental paradigm. It has
been noted that studies which employ selected intervals of
sleep (Yaroush, Sullivan & Ekstrand,1971, Fowler, Sullivan &
Ekstrand, 1973; Barrett & Ekstrand, 1972) confound their re-
tention intervals with time-of-day and circadian placement,
but they tend to implicate stage 4 as beneficial and REM sleep
as detrimental to memory. In contrast, the findings of
studies employing a sleep stage deprivation paradigm (Adelman
& Hartmann,1968; Feldman, 1970; Empson & Clark, 1970;
Ekstrand, Sullivan, Parker & West, 1971; Muzio, 1972) have been
equivocal. The Adelman and Hartmann study and the Empson and
Clark study found REM sleep important to memory. Feldman in-
dicated that the effect of REM, however,may vary with the
nature of the assessment materials. Ekstrand et al. found no
effects of either REM or stage 4 sleep on memory. Finally,
Muzio has noted that any repeated interruption with the normal
sleep cycle may result in decreased retention.

For the studies which found better recall after longer
intervals of sleep (Jenkins & Dallenbach, 1924; Van Ormer,
1932), the findings may again arise from the nature of the
paradigm. These studies confounded the retention intervals
with time-of-day. As shown by Hockey, Davies and Gray (1972)
retention over the early part of the night is superior to
retention over morning intervals, regardless of sleep or
wakefulness. Therefore, Jenkins and Dallenbach and Van Ormer
confounded their studies by testing retention for the wakeful-

ness group over morning and afternoon intervals when LTM is poorest, and testing retention for the sleep group during the evening and night when LTM is best.

It should be noted that time-of-day did not seem as great a factor in forgetting in the present study as it was in the Hockey et al. study. One criticism of the present study could be that the memory task was inappropriate to measure time-of-day effects. However, the long-term and short-term verbal memory tasks in the present study and in that of Hockey et al. were very similar. Both studies employed a list of common nouns, which were presented aloud to the Ss and they were required to write down as many words as they could remember for immediate and delayed recall. Only the length of the lists in the two studies varied. A second criticism which could be raised is that the memory task might have been insensitive to forgetting over 2 hr. intervals or insensitive due to ceiling effects or other peculiarities of the task. However, a series of pilot studies were performed prior to the present study in order to choose an appropriate memory task and to determine how much forgetting would be attained with the task in 2 hr. intervals. In these experiments ceiling effects were not evident nor did the task appear too difficult.

In summary, the present study did not clearly demonstrate diurnal variations in memory. For STM the findings were opposite of that predicted, i.e., rather than decreasing, STM appeared to increase in either capacity or efficiency. However, the effect was not consistent throughout the day nor was it

similar for both verbal and visual STM. For LTM, regardless of sleep or wakefulness, there was virtually no variation with time-of-day. There was a similarity with the Hockey et al. findings, in that sleep appeared to have no effect on memory in the earliest time period while in the evening, sleep appeared to favor both verbal and visual LTM. It should be noted, however, the effect was far from statistical signifi- cance. Finally, although clear differences in stage 4 and REM sleep were established between sleep conditions, there was no significant effect of either stage on LTM. Two explanations were proferred: (a) sleep should have a minimal effect on memory since evidence indicates that consolidation processes may be completed before sleep onset, and (b) the finding that sleep favors memory may arise, in part, as an artifact of the experimental paradigm, since deprivation studies have either favored REM or have been equivocal while selected sleep para- digms have favored stage 4 but have circadian confoundings.

Future investigations in sleep and memory should seek further to unravel the nature of the circadian rhythm on memory, should determine the effects of the experimental para- digm on the findings and, perhaps, should be more theoretically- based than empirically-based, e.g., why should sleep (stage 4 or REM) have an effect upon memory?

APPENDICES

APPENDIX A
VERBAL MEMORY WORD LIST

1.   Apple

2.   Football

3.   Emerald

4.   Trout

5.   Copper

6.   Theft

7.   Hat

8.   Table

9.   Cruiser

10.   Trumpet

11.   Doctor

12.   Head

13.   Wine

14.   Blue

15.   Gasoline

16.   Cotton

SHORT-TERM VERBAL AND VISUAL MEMORY RATIOS

Short-Term Memory Ratios (Verbal)

Subject	8:30 AM		11:30 AM		2:30 PM		5:30 PM		8:30 PM	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
1	2	5	7	3	6	7	6	4	6	6
2	6	5	8	7	7	6	5	6	8	5
3	5	6	8	5	6	6	3	7	7	6
4	6	2	6	7	4	3	5	4	7	5
5	4	3	7	6	6	7	5	2	6	8
6	5	4	4	4	5	7	4	2	7	5
7	7	6	5	6	5	4	5	4	4	7
8	6	4	7	5	5	6	8	8	5	5
9	6	4	7	5	5	4	8	6	8	6
10	8	5	4	6	8	3	4	4	6	6
11	7	4	2	5	8	5	5	6	4	6
12	4	4	5	4	4	4	6	7	6	4
13	6	6	6	5	7	5	7	4	8	5
14	6	4	6	4	7	6	5	7	6	4
15	6	5	6	5	7	6	5	7	7	6
16	7	3	6	4	6	3	5	4	3	4
17	6	8	4	6	5	5	8	4	3	6
18	8	5	5	5	6	7	8	5	6	4
19	4	4	7	8	7	7	6	5	4	5
20	6	4	5	3	7	6	8	8	7	5

Short-Term Memory Ratios (Visual)

Subject										
1	8	3	9	7	8	7	5	6	9	8
2	5	5	7	7	4	8	6	8	10	7
3	9	10	7	5	8	3	9	7	10	6
4	8	5	7	7	9	5	7	7	7	6
5	8	6	10	7	9	8	6	7	8	4
6	7	4	7	4	7	8	9	9	8	7
7	7	3	8	6	4	8	10	8	8	5
8	10	10	6	5	10	9	8	7	7	5
9	5	5	9	9	7	4	10	5	10	7
10	8	8	9	6	7	8	8	5	9	4
11	7	7	9	4	6	8	10	3	8	9
12	9	3	8	8	9	8	9	4	7	4
13	10	6	9	3	7	6	9	5	10	9
14	8	6	9	3	6	4	6	2	9	9
15	9	7	8	6	10	9	9	5	7	8
16	8	3	7	5	8	8	9	7	7	7
17	8	7	8	6	10	9	7	6	9	5
18	7	5	8	5	10	9	7	6	4	7
19	10	8	7	5	10	9	10	10	9	4
20	7	4	10	7	3	3	9	7	6	7

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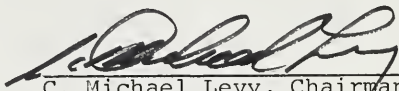
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BIOGRAPHICAL SKETCH

Frederick Lawrence Coolidge was born in Miami, Florida on February 26, 1948. He graduated from Christopher Columbus High School in 1966 where he co-captained the swimming team. He entered the University of Florida and received a Bachelor of Arts degree in 1969 and a Master of Arts degree in 1970.

He is married to the former Helen Jean Adams of Hialeah, Florida and they have two children, Richard and Christa. Frederick is also an avid sportsman and enjoys stereos, the music of Cream, Austin-Healeys, and the works of Tolkien, Brautigan, and Kerouac.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.
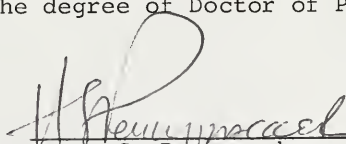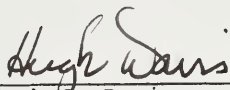
C. Michael Levy, Chairman
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Wilse B. Webb
Graduate Research Professor

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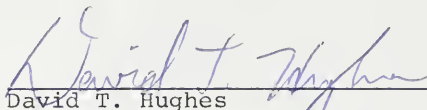
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This dissertation was submitted to the Department of Psychology in the College of Arts and Sciences and to the Graduate Council, and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

August, 1974

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